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FINAL REPORT ON THE EXPERIMENTAL ASSESSMENT OF POROUS SCREENS FOR PROTECTION AGAINST SHOCK EFFECTS

Final Technical Report
by

Dr IM Snyman

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United States Army

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14. ABSTRACT Use the theoretical knowledge of shock attenuation and advance with experimental evidence to the point where the results can be used in practical scenario. Our first objective is to characterise the material with respect to shock attenuation from a blast load. This achieved by the design and development of a test rig that can be used to evaluate, analyse and eventually understand the parameters in a material that influence shock attenuation with verification of the existing theory.			
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DR IM SNYMAN

JANUARY 2006

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Abstract

Use the theoretical knowledge of shock attenuation and advance with experimental evidence to the point where the results can be used in practical scenario. Our first objective is to characterise the material with respect to shock attenuation from a blast load. This achieved by the design and development of a test rig that can be used to evaluate, analyse and eventually understand the parameters in a material that influence shock attenuation with verification of the existing theory

Keywords

Shock attenuation, mitigation, ballistic pendulum, blast wave

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EXECUTIVE SUMMARY

Document:	Title: FINAL REPORT ON THE EXPERIMENTAL ASSESSMENT OF POROUS SCREENS FOR PROTECTION AGAINST SHOCK EFFECTS Report No: DPSS 2005/158 Date: November 2006
Objective:	The objective of this project is to use the theoretical knowledge of shock attenuation and advance with experimental evidence to the point where the results can be used in practical scenario. Our first objective is to characterise the material with respect to shock attenuation from a blast load.
Methodology:	Design and develop a test rig that can be used to evaluate, analyse and eventually understand the parameters in a material that influence shock attenuation with verification of the existing theory.
Conclusions:	The first phase of the design of the rig was successful with regard to the fitment and usage with the ballistic pendulum.
Recommendations:	The next phase to commence so that different foams can be evaluated.
Risks:	None.

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CONTENTS

FIGURES LIST

Abbreviations List

BISRU	Blast Impact and Survivability Research Unit
CSIR	Council for Scientific and Industrial Research
DPSS	Defence Peace Safety Security
mm	Millimetre
MPa	Megapascal
PE4	Plastics Explosive formulation 4
UCT	University of Cape Town

1 INTRODUCTION

The objective of this project is to use the theoretical knowledge (as set out by Gelfand in [4]) and advance with experimental evidence to the point where the results can be used in practical scenario.

Our first objective is to characterise the material with respect to shock attenuation from a blast load. This will entail the design and development of a test rig to be used to evaluate, analyse and eventually understand the parameters in a material that influence shock attenuation with verification of the existing theory.

Our second objective is to use the knowledge and the theory to update or create a mathematical model to be used in finite element software to provide a design tool for engineers. This is typical work that can be done in conjunction with a PhD student at the University of Cape Town

The final objective is to design a prototype application that can be used in the industry.

The outcomes from this research can then be applied to the development and testing of various concepts around the use of porous and other filler materials to effect protection for both vehicles and humans against blast events. Communication of the results will be with technical reports and publications in the open literature.

We are contracted to meet the first objective this financial year. This is the final report and conclude the work done to achieve the first objective.

2 DESIGN OF THE TEST RIG

The test rig has been designed to fit the impulse measurement apparatus at BISRU. The impulse is measured by a ballistic pendulum shown in Figure 1 together with the attachments for this project. The ballistic pendulum consists of a horizontal structure that is accelerated by the explosive on the one side and at the other end the motion is recorded.

Figure 1: The pendulum, test rig and extension tubes

The test rig (attached to the pendulum shown in Figure 2) consist of two flat mild steel plates each with a cylindrical hole, that are bolted together to hold a thinner plate (target plate) in between. On to the one side extension tubes of different lengths can be attached. The other side is attached to the ballistic pendulum. The explosive is placed at the open end of the extension tube and detonated. Various materials can be inserted between the explosive and the target plate.

The impulse on the system is recorded by the ballistic pendulum and the indentation of the plate is measured. The indentation and the impulse measure the energy and shock absorption of the material between the explosive and the target plate.

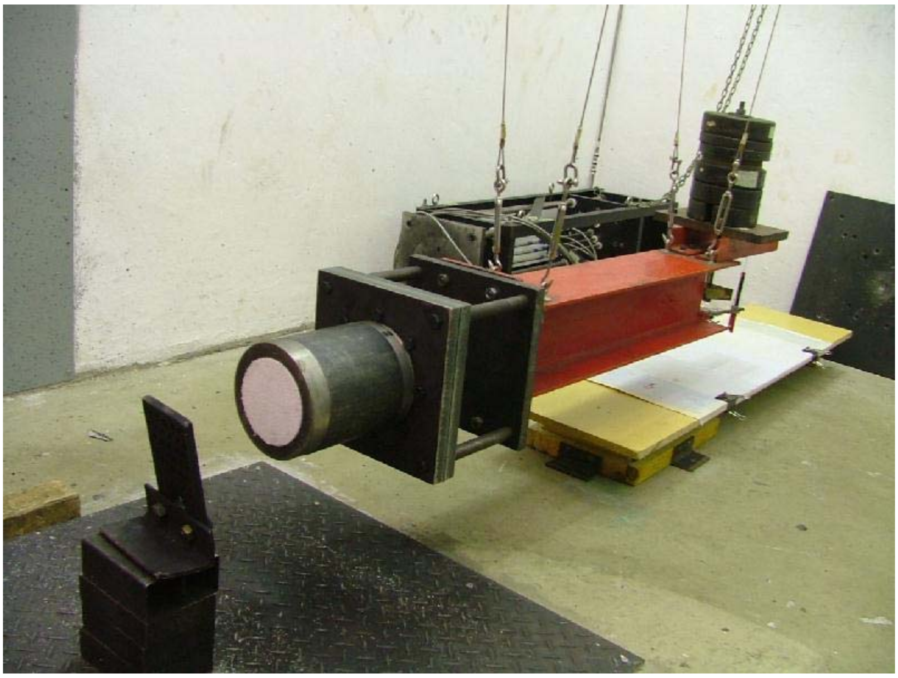


Figure 2: The ballistic pendulum with the test rig fitted

Figure 3: Different extension tubes can be attached to the test rig

The number of test tubes represents the different stand off distance from the target plate. The lengths are 25, 30, 40, 50, 100, 150, 200, 250 and 300 mm. The inner diameter is 106 mm and the outer diameter is 150 mm, shown in Figure 4.

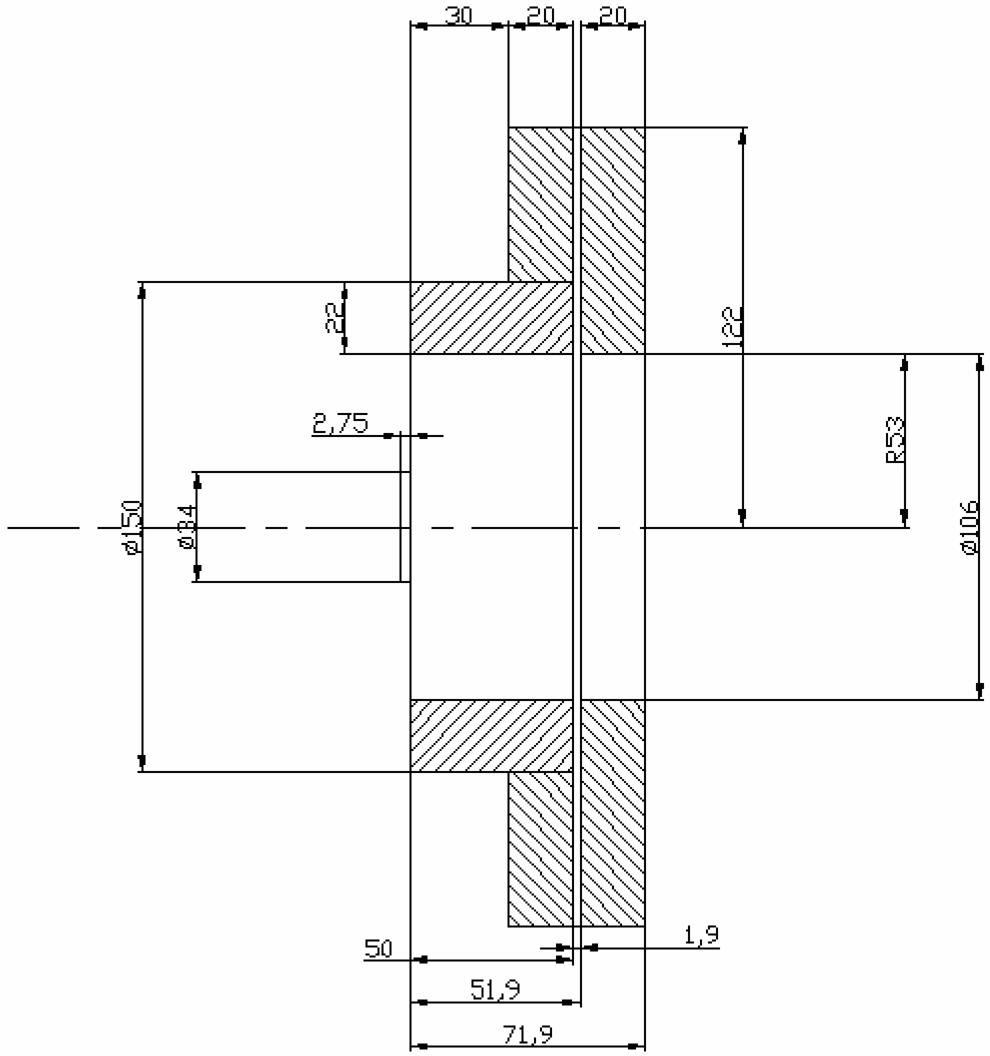


Figure 4: The design of the test tube (length 25 mm) and clamped plates

The material is mild steel, with yields stress 300 MPa. The target plates have different thicknesses, 1.9 mm with yield stress 241 MPa determined from tensile tests. The amount of explosive is varied from 4 g PE4 (or C4) to 15 g. All data will be recorded with air in between the explosive and the target plate and the two sets of data will be recorded for a porous material between the explosive and the target plate. The specific porous material is polystyrene with density 1.6 kg/m^3.

3 EFFECT OF POLYSTYRENE ON BLAST LOADED CIRCULAR PLATES

Nurick and Martin [1] report on experiments conducted by Jones, Uran and Tekin (1970) using various materials (sponge rubber and neoprene) to separate the explosive charge and the test plate to prevent spallation of fully clamped rectangular plates. A significant result of this work was that the type of attenuator, *i.e*. foam or neoprene, did not appear to influence the outcome of the tests, except that the impulsive velocity varied according to the attenuator used [1].

Polystyrene has been used extensively in experiments reported by Nurick et al [1 – 3]. It is used primarily as a stand-off buffer to prevent spalling. It was deemed necessary to understand the possible effects of using polystyrene to separate the explosive charge and plate on measured impulse and plate deformation. Different loading conditions are used in this investigation as shown in Figure 5 and classified as follows,

- ***Loading condition 1 (LC-1)*** – The plastic explosive is attached to a 13mm thick polystyrene pad using a strip of double sided tape and the pad is pushed into place on the end of a tube. Stand off distance is varied using different lengths of tube. This arrangement is shown in Figure 5(a).

- ***Loading condition 2 (LC-2)*** – Double sided tape is used to secure the plastic explosive at one end of the tube, as shown in Figure 5(b).
  Note: *No polystyrene is used.*

- ***Loading condition 3 (LC-3)*** – Double sided tape is used to secure the plastic explosive at one end of the tube. A 13mm polystyrene pad is placed directly against the test specimen as shown in Figure 5(c).

Two charge masses of 5g and 7g were used in this investigation on three stand-off distances 150mm, 200mm and 300mm. The experimental results form the tests for the different loading conditions are given in Table 1.

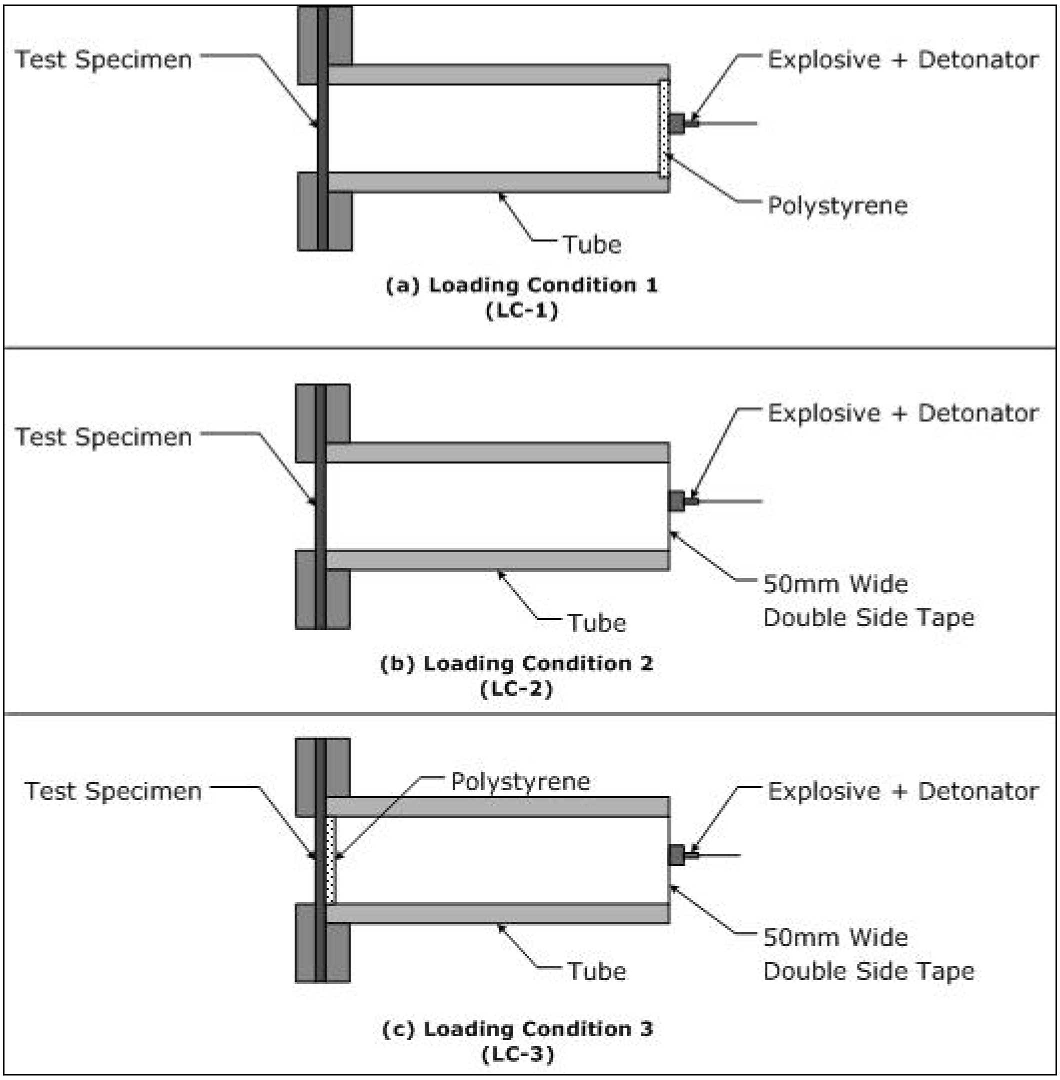


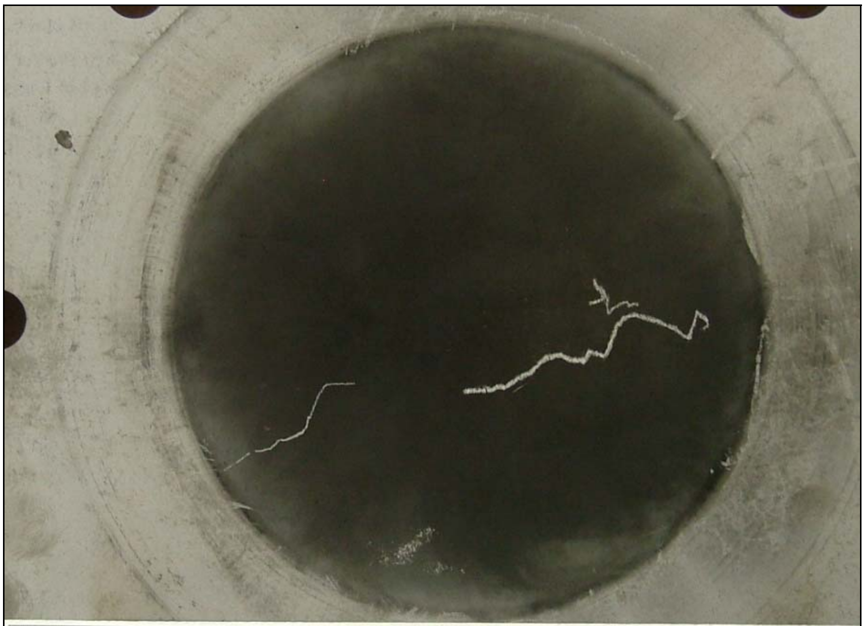
Figure 5: Different loading conditions used in experiments

The experimental observation of the loaded side of the plates for load conditions LC-1, LC-2 and LC-3 at stand-off distance of 300mm are shown in Figure 6 to Figure 8 respectively. The loaded side of a test plate subjected to load condition LC-1 shows an even coating of black soot on the surface of the plate as shown in Figure 6. The charge mass was kept constant and the polystyrene was replaced with double sided tape for load case LC-2, as shown in Figure 7. The loaded side exhibited significantly less black soot than the LC-1 plate. The plate surface was visible and covered with a thin coating of semi-transparent soot which can be easily wiped away as shown in Figure 7. Residue of the polystyrene was visible on the loaded side of the test plate for load case LC-3 as shown in Figure 8. A detailed photograph of the residue is shown in Figure 9. The cross-sectional view of plates subjected to LC-1, LC-2 and

LC-3 for charge mass of 5g and 7g are shown in Figure 10 and Figure 11 respectively.

Table 1 Experimental data for investigation into the influence of polystyrene as a stand-off buffer

Test number	Loading condition	Charge mass (g)	Stand-off distance (mm)	Impulse (Ns)	% variation in impulse from average	Mid-point deflection (mm)	% variation in mid-point deflection from average
NJ230405a	LC-1	5	150	11.47	1.0	7.83	3.0
NJ230405b	LC-2	5	150	12.03	6.0	8.50	5.4
NJ230405c	LC-3	5	150	10.56	7.0	7.87	2.4
			Average	**11.35**	**Average**	**8.07**	
NJ230405d	LC-1	7	150	15.30	0.4	11.76	2.6
NJ230405e	LC-2	7	150	15.11	0.8	12.18	0.9
NJ230405f	LC-3	7	150	15.30	0.4	12.28	1.7
			Average	**15.24**	**Average**	**12.07**	
NJ220405a	LC-1	5	200	11.91	2.2	7.65	2.5
NJ220405b	LC-2	5	200	11.67	0.1	7.82	0.3
NJ220405d	LC-3	5	200	11.38	2.3	8.07	2.8
			Average	**11.65**	**Average**	**7.85**	
NJ220405c	LC-1	7	200	16.18	3.1	10.72	3.2
NJ220405e	LC-2	7	200	15.66	0.3	11.38	2.7
NJ220405f	LC-3	7	200	15.26	2.8	11.14	0.6
			Average	**15.70**	**Average**	**11.08**	
NJ210405a	LC-1	5	300	13.32	3.1	7.01	5.6
NJ210405b	LC-2	5	300	13.20	2.2	7.38	0.5
NJ210405c	LC-3	5	300	12.24	5.3	7.87	6.1
			Average	**12.92**	**Average**	**7.42**	
NJ210405d	LC-1	7	300	16.74	3.1	10.43	0.6
NJ210405e	LC-2	7	300	16.30	0.4	10.27	0.9
NJ210405f	LC-3	7	300	15.65	3.6	10.41	0.4
			Average	**16.23**	**Average**	**10.37**	



Test Number	Plate Thickness (mm)	Stand-off Distance (mm)	Charge Mass (g)	Charge Diameter (mm)	Charge Height (g)	Impulse (Ns)	Mid-point deflection (mm)	Loading
NJ210405a	2	300	5	34	2.75	13.32	7.01	Normal

Figure 6: Photograph of black soot observed for test plate subjected to load condition LC-1, Test plate Number NJ210405a, S = 300mm, I = 13.32Ns and Mid-point deflection = 7.01mm

Test Number	Plate Thickness (mm)	Stand-off Distance (mm)	Charge Mass (g)	Charge Diameter (mm)	Charge Height (g)	Impulse (Ns)	Mid-point deflection (mm)	Loading
NJ210405b	2	300	5	34	2.75	13.20	7.38	Tape

Figure 7: Photograph of translucent soot observed for test plate subjected to load condition LC-2, Test plate Number NJ210405b, S=300mm, I=13.20Ns and Mid-point deflection = 7.38mm

Test Number	Plate Thickness (mm)	Stand-off Distance (mm)	Charge Mass (g)	Charge Diameter (mm)	Charge Height (g)	Impulse (Ns)	Mid-point deflection (mm)	Loading
NJ210405c	2	300	5	34	2.75	12.24	7.87	Tape+poly @ Plate

Figure 8: Photograph of polystyrene residue visible for test plate subjected to load condition LC-3, Test plate Number NJ210405c, S = 300mm, I = 12.24Ns and Mid-point deflection = 7.87mm

Figure 9: Photograph showing a close up view of the polystyrene residue visible for test plate (NJ210405c) subjected to load condition LC-3

Figure 10: Photograph of plate profile for test plate subjected to same charge mass (5g) but different load conditions (LC-1, LC-2 and LC-3) Test plate Numbers, NJ210405a, NJ210405b, NJ210405c

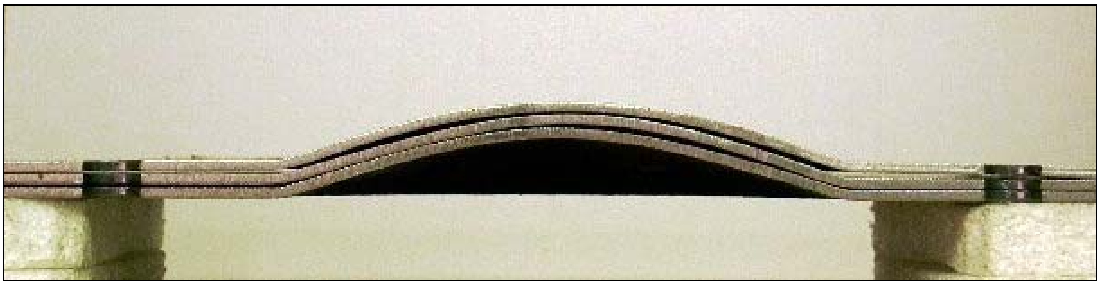


Figure 11: Photograph of plate profile for test plate subjected to same charge mass (7g) but different load conditions (LC-1, LC-2 and LC-3) Test plate Numbers, NJ220405c, NJ220405e, NJ220405f

The results indicate negligible influence on impulse and plate mid-point deflection. The data given in Table 1 are plotted in the graph of mid-point deflection – thickness ratio versus dimensionless impulse ϕ_{cs} as shown in Figure 12. The results show variation in mid-point deflection is less than ±1 deflection – thickness ratio and all the data points fall within the ±1 confidence lines of the empirical prediction equation proposed by Nurick and Martin [1]. The derivation of dimensionless impulse ϕ_{cs} is discussed in detail in the thesis [3].

The measured impulses for loading conditions LC-1, LC-2 and LC-3, in general, show less than 5% variation on the average impulse value for a given charge mass and stand-off distance. The impulse measured for test number NJ230405c shows the largest variation from the average impulse value for that particular charge mass and stand-off distance. The variation in measured impulse (10.56Ns) from the average

impulse value of 11.35Ns is 7%. This translates to a difference in impulse of 0.8Ns from the average impulse value.

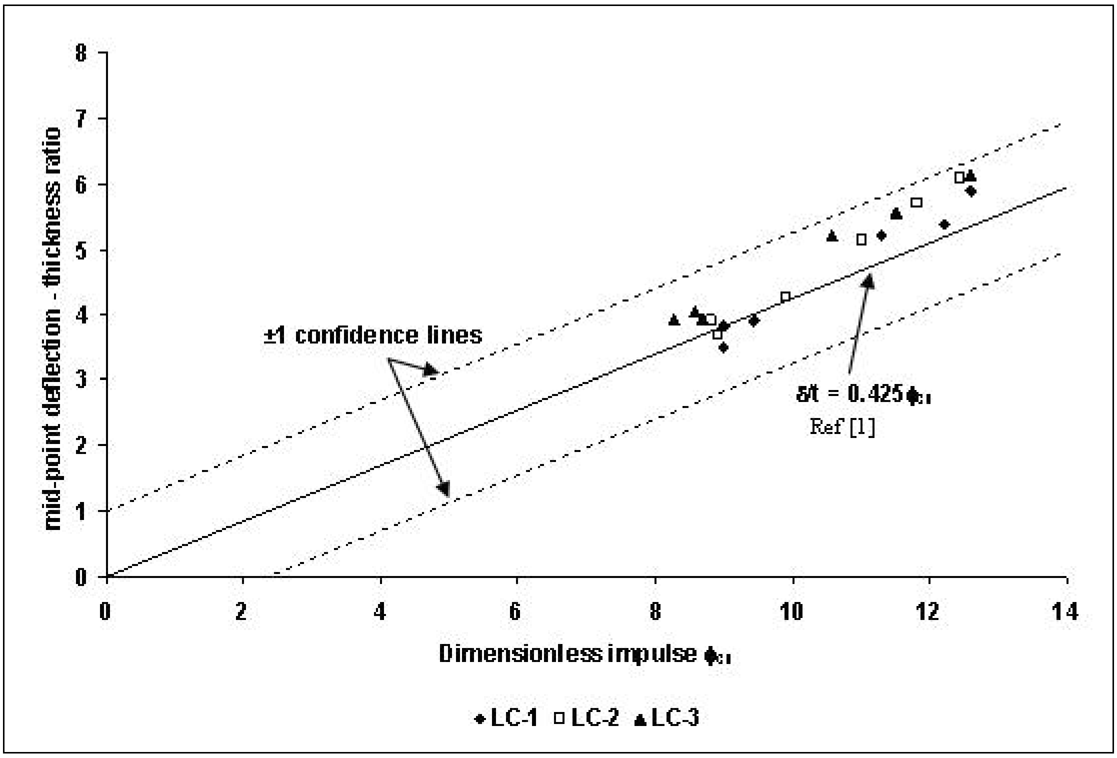


Figure 12: Graph of mid-point deflection - thickness ratio versus dimensionless impulse ϕ_{cs} for data given in Table 1

The experimental results have shown that the effect of polystyrene on plate mid-point deflection and impulse is within experimental error with the experimental set-up used in this investigation.

4 CONCLUSION AND RECOMMENDATIONS

The test rig was designed and commissioned successfully by the student Mr N Jacobs under the leadership of Prof GN Nurick at BISRU, University of Cape Town. In the thesis [3] the design and commissioning are dealt with in detail.

The use of polystyrene as a shock screen material was investigated. The polystyrene has no effect on the impulse delivered by the explosive. The deviations on the measurement of the impulse lie within experimental variation.

Different foam materials (such as metal or aluminium foams) can now be compared with the results of the polystyrene tests.

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